Integration of Decision-Making Components in ERP Systems

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Abstract: Enterprise resource planning (ERP) systems are large modular enterprise applications intended for execution of majority of enterprise business processes with focus on transaction processing. However, the business processes often also require complex decision-making. Data processing logics is deemed as complex decision-making logics if it involves complex analytical calculations and requires domain specific knowledge. This paper reviews existing research on decision-making capabilities of ERP systems and identifies different approaches for integrating decision-making logics in ERP systems. This review leads to an initial framework for integration. This framework evaluates current solutions used in integration. The research findings suggest that decoupling of decision-making logics from ERP systems enables usage of advanced decision-making techniques for execution of decision intensive business processes in real-time though logical integration between decision-making components and business processes should be improved.

1 INTRODUCTION

ERP systems are large modular enterprise applications intended for execution of majority of enterprise business processes. They are primarily geared towards transaction processing. However, many modules contain complex decision-making logics (Holsapple and Sena, 2005). Data processing logics is deemed as complex decision-making logics if it relies on analytical or managerial models for determining course of action in business process execution and often requires domain specific knowledge. Examples of decision-making logics are inventory replenishment and production planning decisions. Bahrami and Jordan (2013) indicate that ERP is to improve the decision-making process at both strategic and operational levels, by providing necessary information, tools and capabilities necessary to enhance the decision-making process.

Traditionally, decision logics is embedded in ERP systems. Companies frequently need to modify this decision-making logic to meet specific requirements (O'Leary, 2008). They have incentives to continuously improve the decision-logics that is a major source of competitive advantage. Frequent modifications are needed as the results. Usually modification is done in the ERP's internal development environment. Results of the modification process are not always satisfactory (Aslan et al., 2012).

Incorporating the decision-making logics into ERP systems has several drawbacks such as inflexibility and cost of changes (Borovskiy et al., 2009). Advances in technology allow for using other technologies for providing decision-making capabilities in ERP systems (Uppström et al., 2015). That includes research on integration of decision-making logics in ERP systems beyond the embedded approach. These approaches include data warehousing and OLAP (Liu and Liu, 2010), model-driven configuration and system thinking (Kurbel and Nowak, 2013), incorporation of the semantic information in structured models (Deokar and El-Gayar, 2013) and a generic association model between planning module and ERP system (Wei and Ma, 2014)

While ERP systems are highly standardized systems, there is no common agreement on role and implementation of decision-making components in ERP systems. The overall goal of the proposed research is to clearly distinguish decision-making components in ERP system to support development, maintenance and utilization of these components. These components should be distinguished both at the logical level and technical level. At the logical

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level, users should well-aware of implication of decision-making components on execution of business processes. At the technical level, decision-making components should modifiable (Uppström et al., 2015), portable (Vidoni and Vecchietti, 2016) and scalable (Aslan et al., 2012).

The objective of this paper is to review existing research on decision-making capabilities of ERP systems and to identify different approaches for integrating decision-making logics in ERP systems. The specific research questions are: 1) what kind of methods are used to provided decision-making capabilities in ERP systems; and 2) what kind of technologies are currently used to implement these methods.

The paper is structured as follows. Section 2 proposes to use an application integration viewpoint to investigate decision-making components and ERP systems and briefly reviews related research. Integration approaches are identified, and the integration framework is proposed in Section 3. Section 4 concludes.

2 BACKGROUND

Decision-making capabilities of ERP systems are integrated from application integration viewpoint (Linthicum, 2003). From this perspective we distinguish: 1) decision-making capabilities as an internal component of ERP systems; 2) decision-making capabilities as external component integrated by data sharing; and 3) decision-making capabilities provided by external components forming an integrated process jointly with ERP data processing capabilities (Figure 1).

The preliminary literature review is conducted following these integration perspectives. Table 1 lists keyword used to identify the relevant literature.

Packaged ERP systems contain many functions for decision-making including functionality for making inventory replenishment, production planning and forecasting decisions. Aslan et al. (2012) evaluates ability of ERP systems to meet requirements characteristic to make-to-order companies. That also includes evaluation of planning and other decision-making capabilities. Samaranayake and Toncich (2007) review manufacturing planning, control and execution in ERP systems. They indicate that there is a variety of strategies and methods available and appropriate case specific configuration of these functions is required. Similarly, multiple forecasting methods are also incorporated in ERP systems and they provide different accuracy and are applicable in specific circumstance (Catt et al., 2008).

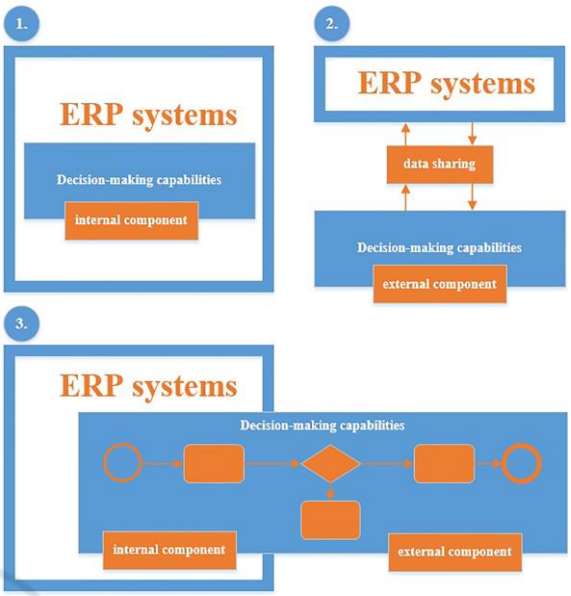

Figure 1: Application integration perspective of decision-making capabilities in ERP systems.

Table 1: Research subject group keywords.

Research subject	Keywords
Internal ERP decision-making capabilities	Enterprise resource planning, decision-making, production planning, inventory management, forecasting, optimization, simulation
Decision-making capabilities provided by other systems integrated with ERP	ERP systems, decision support systems, information systems integration, business intelligence, advanced planning systems
Interfacing between ERP systems and external systems	Service-oriented architecture, decision services, integration standards and formats

Due to unique enterprise requirements, ERP systems often lack the necessary functionality, for example, Nikolopoulos et al. (2003) develop a new module for maintenance management and this module interacts with asset, production and warehouse management modules. ERP systems support decision-making within a single organization but in supply chain management these decisions have profound impact on supply chain partners (Kelle and Akbulut, 2005). ERP systems can serve as a basis for development of such

collaborative decision-making components, for example, "autonomic supply chain" (O'Leary, 2008) and vendor management inventory (Shiau and Tsou, 2015).

To enhance existing decision-making capabilities ERP systems are frequently integrated with other applications. It has been identified that most frequently ERP systems are integrated with Advanced Planning Systems (APS), data analytical systems such as data warehouses and business intelligence and special purposed modelling tools such as simulation tools.

Chou et al. (2005) point out that business intelligence systems use data from ERP systems to support organizational decision-making processes. This is an example of decision-making capabilities provides by external components using data sharing. Recently, Russman et al. (2017) investigated providing data feedback from business intelligence systems to ERP systems. Moon and Phatak (2005) use simulation to check production schedules generated by an ERP system. This approach is further extended by involving APS to generate advanced schedules evaluated using simulation while the ERP system focuses on transaction processing (Krenczyk and Jagodzinski, 2015). Van Nieuwenhuyse et al. (2011) develop an advanced resource planning system, which particularly focuses on fine-tuning of manufacturing planning and control parameters used in ERP systems. Large scale APS typically included functionality for long, mid and short-term planning in areas of supply chain design, master planning, scheduling, transportation and others (Meyr et al., 2015).

The aforementioned papers focus on enhancing functional capabilities while a group of other papers investigate technical aspects of integrating ERP systems with other applications. Integration technologies have evolved significantly ad developments such as service-oriented architecture (SOA) and cloud computing have significant impact of development of decision-making capabilities of ERP systems (Uppström et al., 2015).

Service-orientation allows to decouple decision-making logics from the core application what improves flexibility of decision-making solutions. Zarghami et al. (2012) proposes decision as service to separate decision-making logics from core processes because of specialized nature of these components. An adaptive service regulation architecture and a decision service template let both synchronous request-response interaction and asynchronous notification.

The decoupling of decision-making components requires solutions for simplifying integration between them and other applications including ERP systems. Service-oriented architecture (SOA) coupled with semantic web technologies (El-Gayar and Deokar, 2013) facilitate information exchange functions such as model publication, discovery and use. The similar problems are addressed using model exchange standards such as PMML (Guazzelli et al., 2009). The PMML package exports a variety of predictive and descriptive models from R to XML for usage in other applications. Predictive models in a form of services are proposed by Kridel and Dolk (2013).

Cloud computing allows building distributed and scalable decision-making solutions interacting with ERP systems (Cardoso et al., 2016). The vehicle routing application reported is able to perform computationally intensive tasks and to gather data in real-time from distributed sources such GPS devices mounted on vehicles. Auer et al. (2013) investigate orchestration of services using workflow technologies as a foundation of ERP systems. Specification of decision-making components using domain specific languages allows development of reusable components pluggable in different enterprise applications (Brodsky and Luo, 2015; Brodsky et al., 2015). Wei and Ma (2014) integrates product configuration, production planning and production execution on the basis of the ERP system. The integration is enabled by using a unified feature framework, which ensures information integration among the components.

3 INTEGRATION SOLUTIONS

The review of related work suggests that four integration approaches could be identified. These categories are: 1) embedded; 2) external batch; 3) external real-time; and 4) extended. The embedded approach represents decision-making capabilities implemented inside the ERP system. The external batch approach implies that data from ERP systems are sent to external decision-making applications with or without a direct feedback loop to the ERP systems. This corresponds to data integration. The external real-time implies that decision-making is performed by external components though decisions are made as a part of integrated real-time business process exchanging data with ERP systems. In most cases, these three approaches treat decision-making as general software components. In the case of the extended approach, specific characteristics of decision-making algorithms and models are also

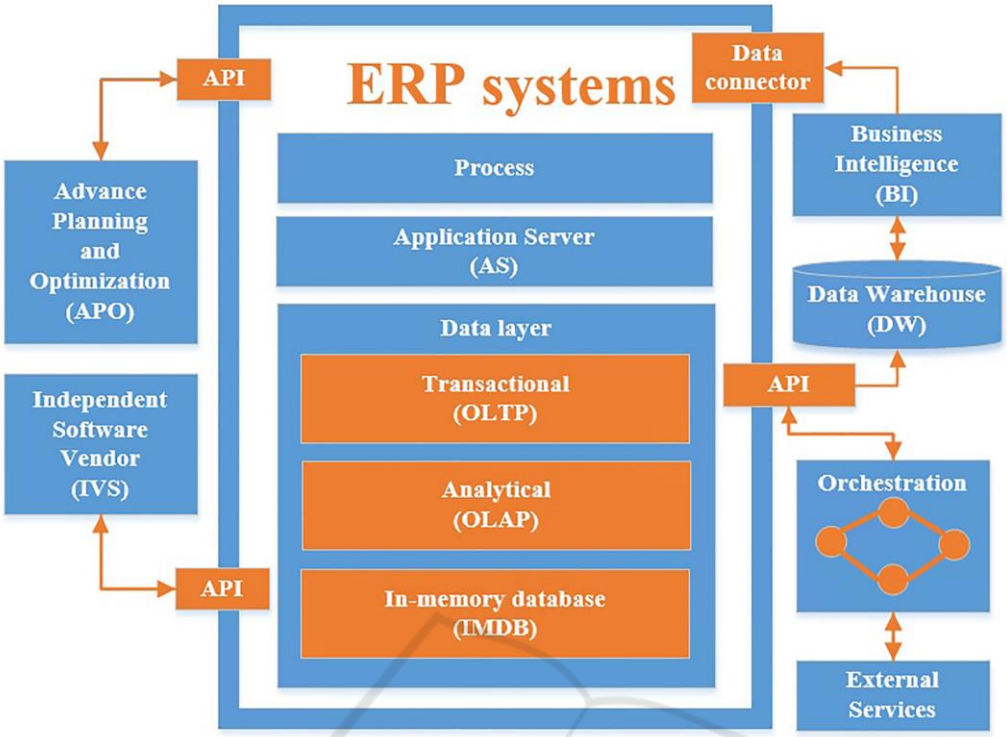

Figure 2: A preliminary framework of technologies used specifically for providing decision-making capabilities in ERP. systems.

taken into account and decision-making capabilities are provided by such model-based components. Table 2 allocates the paper reviewed in Section 2 to the integration categories.

Table 2: Integration approaches used in literature.

Category	Source
embedded	[Aslan et al., 2012], [Borovskiy et al., 2009], [Deokar and El-Gayar, 2013], [El-Gayar and Deokar, 2013], [Guazzelli et al., 2009], [Kridel and Dolk, 2013], [Kurbel and Nowak, 2013]
external batch	[Aslan et al., 2012], [Kridel and Dolk, 2013], [Liu and Liu, 2010], [Vidoni and Vecchietti, 2016]
external real-time	[Cardoso et al., 2016], [Kurbel and Nowak, 2013], [Uppström et al., 2015]
extended	[Aslan et al., 2012], [Brodsky et al., 2015], [Deokar and El-Gayar, 2013], [Kelle and Akbulut, 2005], [Kurbel and Nowak, 2013]

These integration approaches can be implemented using variety of technologies (for instance, Singh et al. (2017) define various integration technologies as a part of the reference architecture for integration platforms). Figure 2 proposes a preliminary framework of technologies used specifically for providing decision-making capabilities in ERP systems.

Embedded decision-making functionality is implemented using internal development tools and executed on application server. Built-in reporting features (Online-analytical processing or OLAP) also support decision-making and in-memory data base technologies are increasingly used to expand internal analytical capabilities of ERP systems (Karduck and Chitlur, 2015). Data warehousing and business intelligence with or without direct data feedback to ERP processes are typical examples of external batch integration approach. Similarly, APS systems are primarily intended for batch integration based on data exchange between the ERP system and the APS. Integrated decision-making intensive processes are typically developed using service-orientation. Services are either invoked directly from the ERP system or using an orchestration engine. The extended approach is supported by a variety of technologies, which are often specific to particular decision-making methods, e.g., predictive analytics or simulation. In this case, decision-making is

preformed by an external component and specific integration protocols are used to ensure data interexchange and integrated process execution with the ERP system.

The evaluation of integration approaches is shown in Table 3. The scalability criterion describes an ability of the decision-making component to deal with computationally intensive problems. The modifiability criterion is considered assuming that decision-making logics requires frequent customization and it is beneficial to separate it from the rest of the application. The data latency criterion indicates whether the decision-making component operates with the most recent data from the ERP systems. The embedded approach has the same level of scalability as an ERP system itself and does not have specific means for handling computationally demanding algorithms. Modifiability is obscured within code for transactions processing and modification might lead to excessive testing of the core part of the ERP systems. However, the embedded approach uses the most recent data. The external batch approach has medium level scalability and modifiability because these are large scale applications and specific decision-making algorithms are not always easy to isolate. The service-oriented systems and micro-service based systems in particular are specifically tailored for achieving scalability and modifiability. The extended approach focuses on interfacing between external decision-making components and ERP systems and integration protocols ought to enable for plugging-in appropriate decision-making components when necessary, thus, facilitating modifiability.

Table 3: Evaluation of integration approaches.

Approach	Scalability	Modifiability	Data latency
Embedded	Low	Low	None
External batch	Medium	Medium	High
External real-time	High	Medium/ High	Low
Extended	Medium/Hig h	High	Low

4 CONCLUSIONS

Decision-making capabilities of ERP systems are analysed through the prism of application integration resulting in four approaches for integration of decision-making components in ERP systems. Current technologies supporting implementation of these approaches are identified and the approaches are evaluated according to the scalability, modifiability and data latency criteria.

The scalability is required because decision-making components often rely on complex computations. The modifiability is required because decision-making logics often needs to be changed during ERP implementation because it provides competitive advantage. Additionally, decision-making logics changes more often than the rest of the application and might require different development competencies. Data latency is important for operational decisions but less so for strategic and tactical decisions. The external real-time approach emerges as suitable for providing decision-making capabilities on ERP systems, especially, for operational decisions. It is argued that decoupling of ERP decision-making logics is beneficial to support scalability and modifiability. That also facilities using the best-of-breed approach to selecting decision-making components without relying solely on components provided by an ERP vendor. However, existing technologies supporting external real-time integration focus on technical rather than logical integration where logical integration is perceived as understanding of relations among decision-intensive business processes and decision-making components. The logical integration is addressed in the external approach. However, the external approach is often tailored for specific decision-making methods and logical integration is not considered specifically in the context of ERP systems.

Thus, the paper identifies the further research direction on generalized interfacing between external decision-making components and decision-intensive business processes supported by ERP systems both at the technical and logical systems. The integration method should support for easy plugging-in of decision-making in ERP systems and exploration of relationships between decisions made and processes performed.

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